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Post-Polio and Elderly Populations

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## INTRODUCTION

In our previous research, we determined that shoulder pain was common in the post-polio population. This pain is thought to result, as least in part, from repetitive use of the arms to assist with weight-bearing during mobility and transfer activities when there is significant weakness in one or more of the muscles in the lower extremities. The increased stress on the upper extremities during these activities results in symptoms of shoulder overuse. In our previous research, we developed a predictive model of shoulder pain that demonstrated a link between lower extremity strength and weight and the presence of shoulder symptoms.<sup>1</sup> However, this research left several questions unanswered, including how much of an effect shoulder pain has on the quality of life in polio survivors and whether our shoulder model, which is based on a post-polio population, could be generalized to other groups with lower extremity impairment. Therefore, the purpose of this project was to study the implications of shoulder dysfunction in the lives of polio survivors and older adults with no history of polio, in terms of effects on functional performance and quality of life, and to determine whether these factors can be significantly improved as the results of a rehabilitation program. We examined the use of an individualized exercise program as a potential means of reducing the burden of both primary and secondary impairments in post-polio and elderly populations and looked at whether it was an effective treatment for improving function and quality of life.

## BODY

### **Study #1: The Effect of Shoulder Dysfunction on Functional Performance and Quality of Life in the Post-Polio and Elderly Populations**

#### **Rationale:**

Although many of the symptoms experienced by polio survivors involve the lower extremities, the increased demand placed on the upper extremities for assistance with weight-

bearing during mobility and transfer activities often cause pain and dysfunction to occur in the shoulder muscles. Similar problems are experienced in other populations with significant lower extremity weakness, including the elderly. A heightened awareness of the complications associated with the weight-bearing upper extremity along with effective treatment options are necessary to keep people with lower extremity impairments functioning as fully as possible in society for as long as possible. Concerns about these individuals' long-term prognosis and ability to continue to maintain active roles in society have directed our attention to the study of shoulder dysfunction and its effect on functional performance in polio survivors and the elderly. The goal of this research is to study the implications of shoulder dysfunction in terms of functional performance and quality of life issues and to determine whether these factors can be significantly improved as the result of an exercise rehabilitation program. Data on disability and function will be used to expand a shoulder model developed as the result of a previous study involving a postpolio population, and the model will be replicated and extended to include elder adults with shoulder pain.

#### **Specific Aims:**

- 1) To collect and compare data on site and severity of musculoskeletal pain, shoulder dysfunction, level of impairment, functional ability, isometric strength, activity level, and quality of life from polio survivors and adults over 60 years of age with no history of polio (also referred to as the control group).
- 2) To examine the relationship between self-reported impairment level and quality of life in polio survivors and controls.
- 3) To determine whether subjects who report a higher degree of impairment are more likely to have shoulder symptoms.

- 4) To improve our understanding of the relation between lower extremity weakness and upper extremity overuse by developing prediction models for shoulder pain using regression analysis techniques.

**Hypotheses:**

- 1) Individuals with higher levels of symptom severity will have significantly reduced functional ability and quality of life compared to individuals with either mild or no shoulder pain.
- 2) The presence of shoulder symptoms can be predicted from lower extremity strength, age, weight, and activity level in the postpolio and elderly populations.

**Inclusion/Exclusion Criteria:**

The inclusion/exclusion criteria for this study were: 1) no major disabilities, such as stroke, amputation, rheumatoid arthritis, or peripheral neuropathy, that could cause muscle weakness, 2) no symptoms of uncontrolled or unstable cardiovascular or respiratory conditions, such as difficulty breathing with exertion, chest pain with activity or at rest, or history of a recent heart attack, which might make a maximal strength test or a walking test unsafe, and 3) no fractures or surgeries within the past six months. In addition, subjects could not be undergoing treatment for cancer (other than skin) and had to be able to ambulate a minimum distance of 30 ft. with or without the use of an assistive device. The study protocol received Institutional Review Board approval and written informed consent was obtained from all subjects.

### **Subjects:**

The project staff was hired in the first quarter, and a project database was designed and implemented as planned. A total of 266 polio survivors (119 male and 147 female) and 390 control subjects (137 male and 253 female) were recruited from the community at large and screened for this study. Of the 656 individuals initially screened, 64 polio survivors and 112 control subjects were excluded because they did not meet the inclusion criteria. An additional 73 polio survivors and 85 control subjects did not participate because of personal reasons (i.e. transportation problems, job conflicts, illness/death in the family, etc.) or they simply did not show up for one or more scheduled appointments. Ultimately, 129 polio survivors (71 males and 58 females) and 191 control subjects (76 males and 115 females) were enrolled in the study. All subjects provided written informed consent before testing.

### **Method:**

All subjects completed a standardized medical history form, which included questions regarding current health status and medications taken on a regular basis. All subjects were also asked to rate their ability to perform five mobility-related tasks on a scale from 0 (unable) to 4 (no difficulty). The tasks included walking 3-4 city blocks, climbing and descending a flight of stairs, pushing a large object, and carrying groceries. In addition, the polio survivors completed a questionnaire that included questions about the original polio infection (e.g. how old they were at the time of infection, what limbs were affected, etc.). Height and weight were measured using a standard scale and a stadiometer. Musculoskeletal pain was assessed using a body diagram. Subjects were asked to shade in the areas on the diagram where they experienced muscle and/or

joint pain on a regular basis. Average pain severity over the past month was then assessed using a scale that ranged from 0 (no pain) to 10 (pain as bad as it can be).

Because the focus of this study was shoulder dysfunction, the subjects also filled out the Shoulder Pain and Disability Index (SPADI), which was designed to assess the relationship between the severity of their shoulder symptoms and the functional status of their shoulder. This instrument has previously been found to be valid, reliable, and responsive to clinical change in patients with shoulder pain.<sup>2</sup> Physical activity level was assessed using the Physical Activity Scale for the Elderly (PASE).<sup>3</sup> This scale was developed for measuring activity level among adults aged 65 years and over. It includes questions about occupational, household, and leisure activities performed during the past week. It has been used previously in studies with polio survivors younger than 65 years based on the assumption that this population is more sedentary than their peers without polio.<sup>4</sup> Scores can range from 0 to over 400, with higher scores indicating higher activity levels. Health-related quality of life was assessed using the SF-36.<sup>5</sup> This instrument consisted of eight dimensions: physical function, physical role limitation, bodily pain, general health, vitality/energy, emotional role limitation, social function, and mental health. Each dimension was measured on a scale from 0 to 100.

Habitual and maximal walking speed were measured for 30 ft. indoors. An estimate of activity intensity level was computed for each subject by dividing habitual walking speed by maximal walking speed. The time required to climb and descend one flight of stairs was also measured. Subjects wore a heart rate monitor while they walked to allow for an objective measure of effort or strain during each mobility task. A subjective measure of effort was also obtained using the Borg scale for Rating of Perceived Exertion (RPE).<sup>6</sup>



All subjects underwent a standardized clinical assessment with respect to the following six signs of shoulder dysfunction:

1. Impingement sign 1: Forcible forward elevation of the humerus with slight internal rotation
2. Impingement sign 2: the arm at 90 degrees of forward flexion followed by forcible internal rotation
3. Pain with arc of abduction to 90 degrees
4. Biceps tendon tenderness
5. Supraspinatus/greater tuberosity tenderness
6. Acromioclavicular joint tenderness

A test was considered positive if the subject acknowledged any shoulder or upper arm pain during the examination. For each positive test, subjects were asked to rate their pain on a visual analog scale (VAS range: 0 – 10) and estimate how long they had been experiencing these symptoms. Symptom tests that had a negative response received a VAS score of zero. Pain or tenderness that was identified by the subject as being related to the exam only was not considered a symptom of overuse and was not included in any analyses.

Maximum voluntary isometric strength was measured in the bilateral hip flexor, hip extensor, hip abductor, knee flexor, knee extensor, shoulder flexor, shoulder extensor, shoulder abductor, shoulder external rotator, and shoulder internal rotator muscle groups in gravity-minimized positions by a physical therapist using a Microfet2 hand-held dynamometer (HHD). The testing positions, stabilization points, and dynamometer placements were standardized and are published elsewhere.<sup>7</sup> For each strength test, the subject pushed against the padded dynamometer force plate, which was held stationary by the physical therapist. Subjects were

told to build to a maximal force over a period of 2-3 seconds and then hold this maximal effort for 3-4 seconds. The peak force was recorded for each trial, within the dynamometer's range of 0 to 100 lbs.

A minimum of two trials was performed for each muscle group. Additional trials were performed only if the first two varied by more than 10%. For very weak muscles with peak strengths of less than 10 lb., additional trials were performed only if the difference between the first two measurements was greater than 1 lb. Subjects were given time to rest between trials, and the maximum number of trials for a single muscle group was set at four to prevent fatigue. If a subject reported pain during testing, those trials were considered invalid. The mean peak strength of the valid trials for each muscle group was used in all statistical analyses.

Subjects were also asked to perform two simple tasks as tests for endurance. For the lower extremity endurance task, subjects were seated with their hips at 90 degrees flexion and their knees at 75 degrees flexion. A five-pound ankle weight was strapped to one leg, just above the ankle. The subject was instructed to lift the leg from 75 degrees flexion to 15 degrees flexion and then lower it back to 75 degrees. This movement was repeated until either the subject felt pain/discomfort or could not lift the leg to at least 20 degrees flexion or for a maximum of 5 minutes. At the end of the test, the number of repetitions was recorded, and the test was repeated on the other leg. For the upper extremity task, subjects had a two-pound weight attached to their wrist and were asked to lift their arm in the plane of the scapula to 90 degrees while keeping their elbow fully extended. Subjects were asked to repeat this movement until either they felt pain, they could no longer lift their arm to at least 80 degrees or for a maximum of 5 minutes.

### **Data analysis:**

Descriptive statistics of the demographic data, strength and endurance measures, functional measures, and summary scores from the PACE, SF-36, and SPADI were computed for both groups. The results are expressed by means and standard deviations. Statistical comparison among the groups was made using the Mann-Whitney U test and the analysis of covariance test.

In order to determine the relation between symptom status and the independent variables for polio survivors and controls, logistic regression techniques were used to develop prediction models. The dependent variable was the presence/absence of shoulder pain. The independent variables, including age, weight, knee extensor strength, hip extensor strength, and activity level (PASE), were converted into quintiles (i.e. each variable was sorted from smallest to largest and then separated into five bins with approximately the same number of subjects in each bin). Plots were made of the proportion of subjects with shoulder pain against the various independent variables. Variables with plots that showed a linear pattern were treated as quantitative. All others were treated as categorical. Univariate logistic regression was performed using a cutoff value of 0.15. Variables that met this criterion were entered into a multivariate analysis, where the p values were calculated relative to the highest quintile for each independent variable. Odds ratios were calculated as a measure of the difference in the proportion of subjects with shoulder symptoms in quintile 5 and the proportion in the other quintiles. The alpha level was set at .05 for all tests. Analyses were performed using SYSTAT Versions 9 and 10 (SPSS Inc., Chicago, IL).

## **Results:**

Data from twelve subjects (three polio survivors and nine controls) were not included in any analyses because of concerns about data validity. Three of these subjects had difficulty following directions during strength testing and other eight had health issues (e.g. parasthesia, severe tremors, etc.) that affected their ability to perform the required study activities. The descriptive information for both groups is summarized in Table 1.

On average, the polio group was younger than the control group ( $p < 0.001$ ). The polio survivors also tended to be taller and heavier than the controls, although there was no significant difference in height, weight, or body mass index between groups for either gender. There was also no significant group difference in activity frequency scores (PACE). However, overall, the polio survivors were significantly weaker and reported experiencing more problems with musculoskeletal pain than the control subjects.

In regard to functional performance, the polio survivors took significantly more time to perform the mobility tasks and rated their exertion levels much higher than the control subjects. However, when looking at changes in heart rate during task performance, there was no difference in performance strain between groups for any of the tasks (with the exception of the maximal walk which had a significant group difference for females only).

In terms of the quality of life measure (SF-36), there were significant differences between groups for all the physical function measures (PF, RP, BP, GH), as well as the social function (SF) measure. Overall, the polio survivors scored significantly lower than the controls on all five of these dimensions, which indicated that the polio survivors were more limited in performing physical activities and experienced more problems with work and other daily activities as a result of their physical health. These physical problems also interfered with their normal social

Table 1. Summary of Descriptive Statistics

<u>Demographics</u>	<u>Gender</u>	<u>Post-polio*</u>	<u>Control*</u>	<u>p-value</u>
Age (yr)	M	62.56 (8.3)	74.30 (6.6)	<b>p &lt; 0.001</b>
	F	62.31 (8.2)	71.81 (7.4)	<b>p &lt; 0.001</b>
Height (in)	M	68.29 (3.2)	67.73 (3.0)	p = 0.309
	F	63.02 (2.8)	62.75 (2.6)	p = 0.365
Weight (lb)	M	187.18 (38.9)	178.10 (31.6)	p = 0.146
	F	154.71 (31.6)	149.37 (30.6)	p = 0.280
BMI	M	28.12 (4.5)	27.30 (4.1)	p = 0.181
	F	27.20 (5.1)	26.74 (5.4)	p = 0.519
<u>Strength<sup>†</sup></u>				
BI-KEX (lb)	M	73.89 (37.5)	91.07 (30.4)	<b>p = 0.003</b>
	F	43.41 (22.9)	61.70 (23.0)	<b>p &lt; 0.001</b>
BI- LEGEXT (lb)	M	114.76 (52.7)	128.21 (40.8)	<b>p = 0.039</b>
	F	68.46 (33.4)	90.35 (32.2)	<b>p &lt; 0.001</b>
BI- LEG (lb)	M	304.40 (110.1)	325.13 (92.2)	p = 0.113
	F	186.81 (78.1)	229.68 (68.6)	<b>p = 0.002</b>
BI-ARM (lb)	M	304.34 (79.0)	297.47 (72.8)	p = 0.537
	F	172.03 (50.4)	187.97 (46.1)	p = 0.088
<u>Musculoskeletal Pain</u>				
% affected	M	76.5%	49.3%	<b>p = 0.001</b>
	F	79.3%	51.4%	<b>p = 0.001</b>
Ave. No. of Sites	M	3.23 (2.7)	2.26 (1.4)	<b>p &lt; 0.001</b>
	F	4.98 (4.8)	2.22 (2.1)	<b>p &lt; 0.001</b>
Ave. Severity <sup>‡</sup>	M	16.18 (19.8)	9.28 (6.9)	<b>p = 0.012</b>
	F	24.68 (20.1)	11.46 (14.6)	<b>p = 0.001</b>
<u>SPADI Rating</u>				
Ave. Pain	M	22.86 (17.3)	14.37 (14.1)	<b>p = 0.021</b>
	F	24.81 (20.7)	20.56 (22.9)	p = 0.291
Ave. Dysfunction	M	28.58 (25.8)	15.06 (17.1)	<b>p = 0.026</b>
	F	36.56 (31.9)	19.28 (31.6)	<b>p &lt; 0.001</b>

Table 1. continued

<u>Activity Score</u>				
PASE	M	146.20 (89.8)	147.80 (61.0)	p = 0.522
	F	124.20 (72.3)	131.09 (74.6)	p = 0.518
<u>Functional Performance</u>				
Habitual speed (m/s)	M	1.04 (0.3)	1.16 (0.2)	p = 0.006
	F	0.85 (0.3)	1.11 (0.2)	p < 0.001
Maximum speed (m/s)	M	1.42 (0.5)	1.81 (0.4)	p = 0.006
	F	1.14 (0.5)	1.64 (0.4)	p < 0.001
Intensity	M	0.76 (0.1)	0.65 (0.1)	p < 0.001
	F	0.74 (0.1)	0.69 (0.1)	p < 0.001
Upstairs time (sec)	M	20.00 (22.8)	10.01 (3.3)	p < 0.001
	F	24.30 (22.3)	12.07 (5.4)	p = 0.012
Downstairs time (sec)	M	16.10 (14.1)	9.42 (3.3)	p < 0.001
	F	19.69 (14.7)	11.38 (5.1)	p < 0.001
Strain – Habitual walk	M	0.94 (0.3)	1.05 (0.3)	p = 0.073
	F	1.02 (0.3)	0.94 (0.3)	p = 0.131
Strain – Maximum walk	M	0.90 (0.3)	0.98 (0.3)	p = 0.174
	F	0.98 (0.3)	0.86 (0.3)	p = 0.025
Strain – Upstairs	M	0.87 (0.3)	0.98 (0.3)	p = 0.054
	F	0.89 (0.3)	0.84 (0.2)	p = 0.702
Strain – Downstairs	M	0.91 (0.3)	1.03 (0.3)	p = 0.123
	F	0.97 (0.3)	0.90 (0.3)	p = 0.352
<u>Perceived Exertion</u>				
RPE – Habitual	M	7.89 (1.8)	7.07 (1.2)	p = 0.008
	F	7.98 (2.0)	6.86 (1.3)	p < 0.001
RPE – Maximum	M	9.52 (2.7)	8.25 (2.3)	p = 0.003
	F	9.75 (2.9)	7.70 (1.9)	p < 0.001
RPE – Upstairs	M	12.03 (2.8)	9.40 (2.5)	p < 0.001
	F	11.92 (3.2)	9.33 (2.3)	p < 0.001
RPE – Downstairs	M	9.97 (2.6)	8.43 (2.3)	p < 0.001
	F	9.92 (2.8)	8.30 (2.1)	p < 0.001

Table 1. continued

<u>Quality of Life (SF-36)</u>				
Physical Function	M	55.60 (26.3)	83.32 (17.5)	<b>p &lt; 0.001</b>
	F	43.69 (26.9)	80.99 (19.7)	<b>p &lt; 0.001</b>
Role – Physical	M	70.52 (36.9)	80.99 (30.6)	p = 0.098
	F	54.89 (41.7)	82.78 (30.2)	<b>p &lt; 0.001</b>
Bodily Pain	M	70.12 (19.3)	81.16 (17.1)	<b>p &lt; 0.001</b>
	F	60.35 (22.5)	78.55 (20.3)	<b>p &lt; 0.001</b>
General Health	M	69.35 (19.4)	78.62 (17.1)	<b>p = 0.003</b>
	F	72.43 (16.7)	78.93 (14.3)	<b>p = 0.016</b>
Vitality	M	56.14 (9.6)	56.34 (9.9)	p = 0.520
	F	56.32 (9.0)	56.55 (10.1)	p = 0.685
Social Function	M	85.45 (19.5)	93.13 (13.7)	<b>p = 0.012</b>
	F	84.48 (21.0)	92.34 (16.0)	<b>p = 0.007</b>
Role – Emotional	M	84.58 (29.8)	85.45 (30.2)	p = 0.743
	F	81.61 (34.9)	83.33 (29.2)	p = 0.855
Mental Health	M	81.44 (12.5)	83.66 (13.0)	p = 0.210
	F	80.63 (13.5)	81.73 (12.4)	p = 0.774

activities. However, there were no significant group differences in the mental health, role-emotional, or vitality dimensions.

Approximately 76% of the polio survivors and 37% of the control subjects reported moderate to severe impairment in one or more of the following activities: walking 0.4 km, climbing one flight of stairs, crouching or kneeling, pushing a large object, or carrying a 10 lb. load. An additional 16% of the polio survivors and 29% of the controls reported a mild degree of impairment in one or more of the same activities. There was no significant difference in age or activity level between subjects who were impaired versus those who were not in either group. Interestingly, the average activity score for the polio survivors at both the mild and no

impairment levels were higher than the average activity scores for the control subjects at the corresponding levels (Figure 1). However, none of the differences were statistically significant.

A closer look at the relationship between impairment level and quality of life revealed that polio survivors who reported moderate-severe levels of impairment also reported significantly lower quality of life score in the physical function ( $p < 0.001$ ), role-physical ( $p = 0.031$ ), bodily pain ( $p = 0.029$ ), general health ( $p = 0.016$ ), and social functioning ( $p = 0.016$ ) dimensions than the controls who reported moderate-severe impairment. However, polio survivors and controls who reported mild or no impairment showed significant differences in the physical function and bodily pain (both  $p < 0.001$ ) dimensions only.

In terms of musculoskeletal pain, the most common symptoms sites were the shoulders, mid-low back, and the knees for the postpolio group, and the knees, shoulders, and ankles/feet

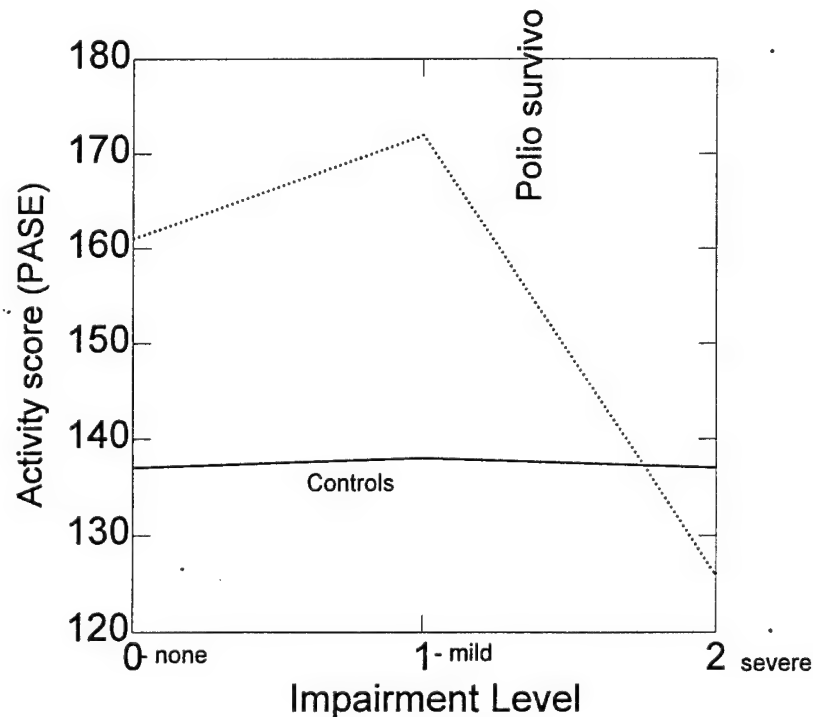


Figure 1. Activity level vs. Impairment Level for Both Groups



for the control group. Approximately 80% of the polio survivors reported experiencing pain on a regular basis, compared to about 50% of the control subjects. Among those subjects who reported any musculoskeletal symptoms, 63% of the polio survivors and 39% of the control subjects reported experiencing shoulder pain with daily activity. The shoulder pain and disability ratings were significantly higher for the male polio survivors than the male control subjects (Table 1). However, the female polio survivors and the female controls differed significantly in disability ratings only. The female polio survivors reported higher ratings for shoulder disability than the female controls, but their pain severity ratings were similar (Table 1).

In the post-polio group, there was no evidence of a relationship between self-reported impairment level and the incidence of shoulder pain. However, among controls, there was a trend for subjects who reported moderate to severe levels of mobility impairment to be more likely to have shoulder symptoms compared to subjects with mild or no impairment ( $p = 0.056$ ).

For the polio survivors, univariate logistic regression analysis with presence or absence of shoulder symptoms as the dependent variable showed that weight and knee extensor strength had  $p$  values below the 0.15 cutoff. When these variables were put into a stepwise multivariate logistic regression analysis, the results showed that both weight and knee extensor strength were significant predictors. The  $p$  values and odds ratios for the model are listed in Table 2. The results for weight did not show a consistent pattern. However, a plot of the proportion of subjects with shoulder symptoms versus knee extensor strength (in quintiles) revealed a threshold effect. The proportion of subjects with symptoms was significantly higher when bilateral knee extensor strength was less than 59 lb. than when it was more than 59 lb.

A similar regression analysis was performed for the control group. Unfortunately, none of the independent variables selected met the 0.15 cutoff criterion for inclusion in the multivariate model.

A separate analysis of the relation between general musculoskeletal pain and activity level was performed on a subset of 54 polio survivors and 54 controls, who were matched for gender, race, and bilateral knee extensor strength. The results of this analysis indicated that polio survivors reported significantly more symptoms than the matched controls ( $p < 0.05$ ). Symptom status among the polio survivors was strongly associated with performance strain in the maximal walking task, perceived exertion in the habitual walking task, and activity intensity. While the polio survivors had activity frequency scores (PACE) and habitual walking speeds similar to those of the matched controls, there was evidence that they performed the activities at higher intensity levels. The polio survivors who performed the activities at higher intensity levels were more likely to report problems with moderate to severe pain and more mobility difficulties.

Table 2. Prediction Model for Shoulder Symptoms in Polio Survivors

Variable*	p value	Odds ratio	Confidence Interval	
			Upper	Lower
Constant	0.006			
Knee extensor	0.004	0.313	0.686	0.143
Weight - 1	0.049	0.103	0.987	0.011
Weight - 2	0.331	0.320	3.174	0.032
Weight - 3	0.030	0.044	0.734	0.003
Weight - 4	0.366	2.883	28.676	0.290

\*Variables are in quintiles (1-4). Each quintile was compared with quintile 5.

## **Discussion:**

Despite having significantly greater leg extensor weakness, the polio survivors maintained an activity frequency level, as measured by the PACE scale, that was comparable to that of the controls. However, since the polio survivors' capacity for speed while performing mobility activities was significantly lower than the capacity of the controls, the end result was that polio survivors were performing at higher activity intensity levels. In other words, the difference between the polio survivors' normal speed and their maximum speed was significantly smaller than that for the controls. Polio survivors also rated their perceived exertion significantly higher than the controls for all the mobility tasks. We would have expected this increased effort to be reflected in the strain measures, which are based on changes in heart rate during task performance. However, we did not see any significant group differences in strain measures for any of the tasks, except the maximum speed walking task among females only.

The results of this study indicated that shoulder symptoms were more common among females than males in both the postpolio and control groups. Females in both groups also reported higher levels of shoulder pain and disability. The regression analysis for polio survivors confirmed the existence of a relationship between presence of shoulder symptoms and knee extensor strength and weight in this group. Similar results were documented in an earlier study<sup>1</sup> and provides support for our hypothesis that there is a link between shoulder symptoms and lower extremity strength. Weak knee extensors may cause increased demand on the arms during tasks such as getting up from a chair or using an assistive device for ambulation. However, although the two models contained the same variables, there were some differences. In the original model, we identified 79 lbs. as the threshold level for bilateral knee extensor strength, while in this study the threshold was 59 lb. One possible explanation for this difference

is related to how the quintiles were defined. The cutoff points for each quintile were slightly different between studies. When an analysis was attempted using the quintile cutoff points from the original study, we did not have a sufficient number of subjects in each grouping to run a formal analysis. However, we did examine the proportion of subjects with shoulder symptoms in each group and found that none of the subjects in the higher groups (#4 and #5) had shoulder symptoms, while the proportion of subjects with symptoms in groups #1-#3 varied from 33-50%. The threshold in this model was 57.6 lb. It is clear that more research is needed to determine whether the relation between upper extremity overuse symptoms and lower extremity strength can be adequately explained using a threshold model or if a curvilinear model is more appropriate.

## **STUDY #2: The Effectiveness of Exercise on Shoulder Dysfunction in Post-Polio and Elderly Populations**

### **Rationale:**

Although many of the symptoms experienced by polio survivors involve the lower extremities, the increased demand placed on the upper extremities for assistance with weight-bearing during mobility and transfer activities often cause pain and dysfunction to occur in the arms, particularly the shoulder muscles. Shoulder pain is a major problem among polio survivors and is associated with a significant reduction in the quality of life in this population.

Similar problems are also experienced in other populations with significant lower extremity weakness, including the elderly. There is a need for a heightened awareness of the complications associated with the weight-bearing upper extremity. More information is also

needed on which treatment options are most effective in keeping people with lower extremity impairments functioning as fully as possible in society for as long as possible.

Theoretically, exercise training is a potential means of reducing the burden of both primary and secondary impairments in people who have lower extremity weakness and shoulder pain. Therefore, the objective of this study was to compare the effectiveness of two different exercise programs (one that focused on the shoulder muscles and one that focused on the lower extremity muscles) alone and in combination in reducing shoulder pain in polio survivors and older adults with lower extremity weakness. These results were compared to those from a control group who received relaxation or stress management therapy for their shoulder pain.

#### **Specific Aims:**

- 1) To determine whether exercise training is a potential method of reducing the burden of impairments in the post-polio and elderly populations.
- 2) To compare the effects of different types of exercise programs to determine which is most effective in reducing shoulder pain and disability.

#### **Inclusion/Exclusion Criteria:**

Polio survivors and controls who participated in Study #1 and who met the following criteria were recruited for this study: a) pain in one or both shoulders during activities of daily living, b) no deformity other than that associated with polio, c) no sign of inflammation or swelling in the shoulders, d) ability to do 10 repetitions of one of the target exercises with the lowest resistance Theraband. Subject exclusion criteria were: a) peripheral neuropathy, b) positive lag test, c) positive spurling test with pain radiating from neck, d) positive sulcus test

(i.e. an unstable shoulder), and e) positive drop arm test which is indicative of a rotator cuff tear. Potential subjects were also excluded if they had shoulder surgery in past six months; had a history of macrotrauma to the shoulder, or had significant upper extremity weakness that prevented them from using their arms to push out of a chair. In addition, subjects could not be receiving any type of treatment or therapy for their shoulder pain or other co-existing medical conditions.

### **Subjects:**

Forty-eight polio survivors and 32 older adults with shoulder pain were identified for possible inclusion in this study. There were 12 additional subjects (11 polio survivors and 1 control) who met all criteria except the one for strength. A total of 30 polio survivors and 20 older adults were enrolled in this study. Thirteen of these subjects (7 polio survivors and 6 older adults) did not complete all the required visits. Six subjects were disqualified after the initial evaluation because their shoulder pain resolved prior to the intervention, and another subject was disqualified because he was unable to perform the required exercises due to lack of strength. Four other subjects withdrew from the study after they began medical treatment for problems unrelated to their study involvement. One subject withdrew because she did not like her group assignment, and another subject was dropped by the PI after he missed a scheduled appointment and failed to respond to multiple attempts to reschedule.

### **Method:**

Subjects were randomly assigned to either one of three exercise groups or the relaxation therapy group. Members of the first exercise group received an individualized exercise program designed to increase the strength and flexibility of their shoulder muscles. Members of the

second exercise group received exercises for their lower extremities, especially the knee extensor and hip extensor muscles, and members of the third exercise group received a combination of both types of exercises.

Although the specific exercises were individually tailored, the principles of prescription were standardized across subjects. The treatment consisted of a graduated exercise program based on the subject's initial level of weakness. Each subject received an average of six exercises in their program, and the frequency of exercise was three to four days per week on non-consecutive days. The exercises were performed at submaximal levels and structured according to the guidelines of the American College of Sports Medicine. Each exercise program was designed to provide a challenge to the functional capacity of the individual without causing excessive fatigue and/or muscle soreness. The program combined stretching and flexibility exercises with strengthening exercises using Theraband. When appropriate, subjects progressed from no resistance to light and medium resistance for each exercise.

During the first week, the resistance exercises were performed using the lowest level of resistance. During this period, the emphasis was on proper technique and motor learning, while minimizing the risk of significant irritation of the shoulder symptoms. Subjects were instructed on how to monitor their fatigue level using the Borg scale for perceived exertion. Every 2-3 days during the first week, the therapist contacted each subject by phone to check on how they were doing with the exercise program or the stress management program and to give them encouragement. Throughout the study, all subjects received the same amount of attention and contact with the physical therapist, both in terms of visits to the research clinic and phone calls to help maximize study compliance and minimize the drop-out rate.

Approximately 7-10 days after their initial visit, subjects were asked to return to the research clinic to review their treatment programs with the therapist and to make sure they were not experiencing any problems. If a problem was identified, the treatment program was modified. For the next 16 weeks, subjects were seen in the research clinic on a monthly basis to have their shoulder symptoms and strength re-evaluated. Modifications to the treatment programs, which included either increasing the resistance level for the various exercises using new Theraband and/or modifying which exercises were included in the subject's program, were also made at each visit. All subjects were asked to keep a log where they recorded which days the exercises were performed and the number of repetitions completed. At the end of each week, subjects also were asked to rate their level of shoulder discomfort over the previous week on a VAS scale. This rating was used to monitor the ongoing treatment program. Additional phone calls were made periodically by the physical therapist throughout the duration of the study (i.e. once a week during weeks 3-6 and every other week during weeks 7-16) to help with compliance and monitoring of the treatment programs.

Subjects in the relaxation group were requested to maintain their current level of activity as much as possible and to refrain from starting any form of exercise program for the duration of the study. Participants randomized into the relaxation program received instruction on a variety of breathing techniques, muscle relaxation, body stretching and extension and mental imagery. A predetermined number of the different techniques were progressively introduced at each follow-up visit, so that by the last evaluation each subject's program consisted of 15 techniques. Subjects were provided with standardized guidelines for completing the program.

At each follow-up visit, subjects performed their complete program so that the physical therapist could review their technique and provide feedback. As with the exercise program,



subjects were asked to keep a log of when they performed their program, instructed to monitor their fatigue using the Borg scale on a daily basis, and to indicate an average pain level using a VAS scale at the end of each week. Subjects were also contacted by phone to discuss their program with the frequency of contact mimicking that of the exercise programs.

At the last visit, the functional performance tests and the endurance tests were repeated for all subjects along with the symptom and strength assessments. Subjects were also asked to complete the PACE and SF-36 questionnaire.

#### **Data analysis:**

Descriptive statistics for the demographic and outcome measures were computed. Differences from baseline were calculated for all primary and secondary outcome variables. Response to treatment or degree of symptom resolution was quantified in terms of the change in the mean SPADI pain and disability scores. Between group comparisons were analyzed unpaired t-tests. All analyses were performed using SYSTAT10.

#### **Results:**

The demographic information and baseline dependent variable measurements were calculated by group (Table 3). Results after the 16-week intervention showed a decrease in shoulder pain and disability ratings in all treatment groups (Figures 2 and 3). After adjusting for baseline values, the largest decrease in shoulder pain was seen for Groups 1 and 3, where pain ratings decreased by 58.2% and 49.5% respectively. Smaller improvements were seen in Groups 2 (19.9%) and 4 (34.4%).

Table 3. Descriptive Statistics

Variable	Group1	Group 2	Group 3	Group 4
Group (n)				
Postpolio	8	5	7	3
Elderly	5	3	3	3
Gender (n)				
Men	9	3	2	2
Women	4	5	8	4
Age (yr)	66.46 (9.8)	61.13 (11.7)	63.80 (9.8)	71.83 (7.1)
Height (in)	66.33 (3.4)	66.78 (3.5)	63.44 (3.4)	64.08 (4.7)
Weight (lb)	165.00 (35.2)	188.13 (36.4)	160.70 (28.0)	160.67 (9.4)
SPADI score:				
Pain	18.62 (11.9)	35.88 (19.0)	18.20 (9.6)	32.00 (31.1)
Disability	20.62 (18.8)	38.00 (24.0)	17.60 (14.1)	43.67 (56.0)

Figure 2. Change in SPADI Pain Scores

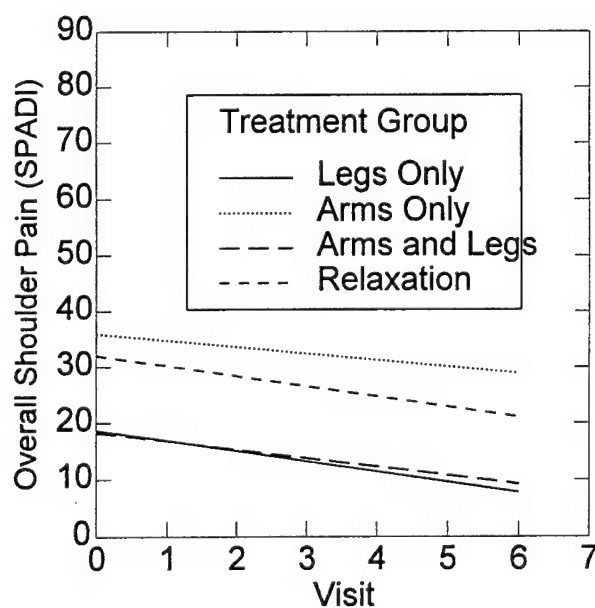
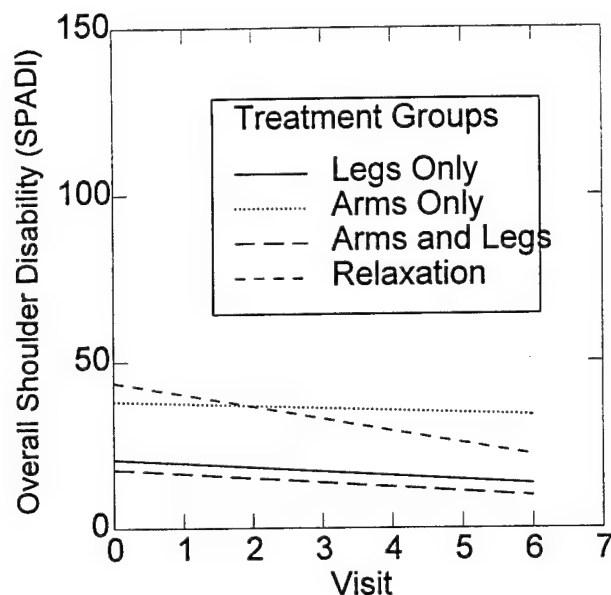


Figure 3. Change in SPADI Disability Scores



The largest change in shoulder disability score was seen for Groups 4 and 3, which showed decreases of 50% and 45.5% respectively. The average change in disability score for Group 1 was 35.8% and 11.5% for Group 2.

Comparison of the pre- and post-intervention strength values for the bilateral knee extensors, combined hip and knee extensors, overall leg and arm showed no significant change ( $p > 0.05$ ) in any of the strength measures for any of the groups (Table 4). However, there was evidence of a slight, but statistically insignificant increase in the combined hip and knee and the overall leg strengths in Groups 2 and 3. This was not surprising considering that these were the two groups that included leg exercises as part of the intervention. The relaxation group was the only one to show decreases in all four strength measures. However, there was also a slight decrease in average arm strength seen for Group 2.

There was no significant change in activity level (PACE) for any of the groups, and the results for the endurance measures were inconsistent with no clear trends evident.

Table 4. Summary of Baseline Measures, Difference Scores, and Effect Sizes for Each Treatment Group

Variable	Group 1			Group 2			Group 3			Group 4		
	Baseline Value	Difference Score	Effect Size	Baseline Value	Difference Score	Effect Size	Baseline Value	Difference Score	Effect Size	Baseline Value	Difference Score	Effect Size
PACE	166.23 (81.3)	-13.18	-0.145	178.47 (62.5)	19.78	0.308	177.91 (45.3)	28.01	0.314	132.80 (57.0)	6.08	0.140
<b>Strength:</b>												
BI-KEX (lb)	62.85 (34.0)	1.46	0.161	61.88 (32.6)	6.57	0.531	54.70 (26.6)	11.20	0.661	53.33 (27.1)	-0.60	-0.053
BI-LEGEXT (lb)	96.23 (50.4)	3.64	0.215	85.25 (38.2)	11.71	0.623	82.76 (45.1)	19.90	0.891	86.00 (41.3)	-8.40	-0.499
BI-LEG (lb)	256.12 (115.3)	3.31	0.082	218.95 (79.2)	21.97	0.517	227.86 (117.6)	28.58	0.602	216.33 (97.0)	-23.60	-0.595
BI-ARM (lb)	225.54 (85.2)	5.91	0.272	223.63 (91.5)	-16.71	-0.476	205.48 (80.5)	4.78	0.299	166.37 (70.1)	-17.08	-0.609
<b>Mobility:</b>												
Max-Walk (m/s)	1.26 (0.3)	0.10	0.404	1.43 (0.5)	0.09	0.462	1.35 (0.4)	0.05	0.472	1.13 (0.4)	-0.04	-0.222
Norm-Walk (m/s)	0.90 (0.3)	0.01	0.071	1.02 (0.3)	0.02	0.165	0.92 (0.2)	-0.01	-0.042	0.84 (0.2)	0.03	0.653
Up Stair Time (s)	15.73 (6.9)	0.43	0.077	17.01 (12.5)	-1.19	-0.353	15.88 (9.9)	0.72	0.186	21.80 (18.7)	1.30	0.505
Dn Stair Time (s)	13.98 (7.7)	-1.07	-0.358	14.69 (10.1)	-0.35	-0.170	11.17 (3.7)	-0.42	-0.370	18.43 (15.4)	4.77	0.769
<b>Rating of Perceived Exertion (RPE):</b>												
Max-Walk	9.33 (3.1)	-0.42	-0.145	9.63 (2.6)	1.00	0.433	9.82 (1.7)	-0.82	-0.335	10.17 (2.6)	0.17	0.104
Max-Norm	7.82 (2.2)	-0.82	-0.654	7.88 (1.6)	1.13	0.699	7.64 (1.6)	0.55	0.247	8.17 (2.0)	1.00	0.598
Up Stairs	11.42 (2.9)	-0.67	-0.275	12.25 (2.1)	0.25	0.242	11.09 (2.5)	-0.91	0.439	13.00 (4.0)	1.00	0.337
Dn Stairs	10.17 (4.2)	-0.83	-0.243	10.50 (2.6)	-0.13	-0.092	9.91 (2.1)	-0.09	-0.036	10.50 (3.9)	0.83	0.360
<b>SF-36 score:</b>												
Physical function	51.92 (25.7)	3.46	0.304	46.88 (24.8)	3.13	0.100	71.50 (25.1)	-7.00	-0.761	49.17 (28.9)	-0.83	-0.104
Role - Physical	53.85 (40.6)	-3.85	-0.095	43.75 (29.1)	3.13	0.100	70.00 (36.9)	0.00	-	37.50 (37.9)	9.17	0.636
Bodily Pain	68.23 (15.7)	7.54	0.584	43.88 (9.1)	9.50	0.792	61.00 (14.7)	3.10	0.122	46.83 (21.5)	5.33	0.552
General Health	65.54 (20.0)	-0.39	0.022	58.86 (20.8)	-2.43	0.225	70.30 (11.1)	2.10	0.172	66.33 (25.6)	10.00	1.299
Vitality	54.62 (9.7)	1.54	0.150	51.88 (9.6)	0.63	0.073	54.50 (12.3)	-1.67	-0.126	56.67 (6.8)	3.33	0.323
Social Functioning	84.62 (17.0)	-2.89	0.133	62.50 (24.1)	14.06	0.503	92.50 (12.1)	-3.75	-0.212	79.17 (28.1)	4.17	0.133
Role - Emotional	79.49 (25.6)	-15.39	-0.347	83.33 (25.2)	-4.17	0.100	96.67 (10.5)	-6.67	-0.316	72.22 (44.3)	7.78	0.627
Mental Health	80.31 (13.2)	0.62	0.060	75.50 (14.9)	-2.00	0.063	80.80 (7.0)	-0.40	-0.063	81.33 (7.0)	0.67	0.072

## **Discussion:**

This study was designed to compare the effect of four different interventions on the shoulder pain and disability in polio survivors and older adults with lower extremity weakness. Previous research had indicated that therapies that include exercise of the lower extremities may reduce shoulder overuse symptoms. This study improved on the design used in the previous study by allowing the exercises to vary in resistance so that gains in strength were more likely. Unfortunately, many potential subjects who had shoulder pain did not have the strength necessary to perform 10 repetitions with even the lowest resistance band. As a result, we ended up with a very small sample size and did not have the power to make any definitive conclusions about the efficacy of the interventions. Group 3, the combined leg and arm exercise group, showed improvements in shoulder pain and disability as well as lower extremity strength, but also showed decreases in the largest number of quality of life dimensions compared to the other groups. On the other hand, Group 4, the relaxation group, showed the most improvement in shoulder disability and quality of life scores, but showed decreases in every strength measure.

It is apparent that factors other than strength may have been influencing the improvement in shoulder symptoms among subjects in this study. For example, both relaxation and exercise therapies are associated with decreased levels of depression, anger, and stress.<sup>8</sup> Since many of the outcome variables were subjective in nature, it is possible there may have been a placebo effect with subjects' symptom ratings being influenced by their expectation of improvement. Additional research is needed to determine whether any of these interventions will be useful in preventing or delaying the onset of shoulder problems in polio survivors or older adults with lower extremity impairments.

### **STUDY #3: Analysis of Functional Performance During a Chair Rise Task Before and After Participation in an Exercise Treatment Program**

#### **Rationale:**

Understanding how strengthening affects the biomechanics of task performance in the presence of pathology can clarify the role of strength changes in improving function. Therefore, the major focus of this study was to determine how changes in strength and resolution of musculoskeletal symptoms due to an exercise program would affect functional performance associated with standing from a chair. It was assumed that the custom exercise program would increase strength in the upper and/or lower extremities and would simultaneously reduce shoulder symptoms.

#### **Specific Aims:**

- 1) To determine if an exercise program will improve the ability to perform a common functional task (chair rise) in terms of time to complete the task and lateral symmetry of kinematic and kinetic variables.
- 2) To determine the effect of an exercise program on upper extremity loading patterns.

#### **Hypotheses:**

1. Increased lower extremity strength will result in the lower extremity carrying more of the load to propel the body during the sit-stand task. Correspondingly, upper extremity forces should be reduced.

2. Increased lower extremity strength will give rise to less forward trunk lean, earlier arm release, and less forward and/or upward velocity. These are stability and propulsion techniques that may be less necessary with increased lower extremity strength.
3. Decreased upper extremity symptoms will be reflected in increased agonist upper extremity EMG due to more dependence on upper extremity muscles and less dependence on upper extremity passive tissues. Specifically, we predict an increase in triceps and post-deltoid and maybe lateral deltoid electromyographical (EMG) activity.
4. Decreased co-contraction in upper extremity agonist-antagonist pairs due to reduction in the “stiffening” and the “letting go” approach as upper extremity symptoms resolve.

**Inclusion/Exclusion Criteria:**

Polio survivors who did not wear a locking knee brace and were enrolled in either the lower extremity strengthening group, the upper and lower extremity strengthening group, or the relaxation group in Study #2 were eligible to participate in this study.

**Subjects:**

There were a total of 18 polio survivors who participated in Study #2 and were approached for possible participation in Study #3. Two of these individuals wore locking knee braces and had to be excluded from this study. Three polio survivors were unwilling to participate because of the time commitment, and four others were not tested because the gait lab was unable to do the pre-intervention testing within the time period between the subjects' enrollment in Study #2 and initiation of their exercise/relaxation program. The remaining nine polio survivors were enrolled and provided written informed consent prior to testing. One

subject later withdrew from the treatment study and therefore was unable to complete his post-intervention testing for this study. Of the remaining subjects, five were enrolled in the combined upper and lower extremity strengthening group, two were enrolled in the lower extremity only strengthening group, and two were enrolled in the relaxation group.

### **Methods:**

Data collection and analysis procedures were followed as outlined in the original proposal. Contact forces between the feet and the ground, contact forces between the arms and the armrests, bilateral surface EMG of six muscles in each arm, arm strength data, and body movement data were collected. Additional details of the EMG collections and analysis procedure are given here due to the relative novelty of the methods developed for those data.

The methods were devised to allow quantitative assessment of changes in muscle activity and amount of co-contraction due to the exercise program. The basic premise was that the dynamic EMG (i.e. that recorded during sit-stand performance) from each test session was normalized to the EMG from a known value of the subject's submaximal effort. Doing so accounted for many of the factors that produced variability and normally impede comparison of EMG across test sessions. Each subject's own 30% force level was the normalization factor for each muscle group. A submaximal level has been reported to be ideally useful for intersubject comparison across sessions.<sup>9</sup> The 30% level was selected as it was anticipated to be safe and one that the subjects could attain and hold without much difficulty or practice. A hand held dynamometer with real-time digital readout was used to assess the force level achieved by the subject. A contact switch was manually triggered when the subject obtained the desired level to allow identification of the EMG record to use during data processing. EMG activity was



recorded for three repetitions from each muscle at the 30% level. A standardized procedure to isolate each muscle being tested was followed based on recommendations for muscle testing. Isolation was critical to minimize the ability of substitution of muscles other than the one being tested to contribute to the target force.

Normalizing the dynamic EMG recordings to the subjects' submaximal level framed the dynamic EMG in terms of "effort". The "units" of the normalized dynamic EMG signal were then relative to the EMG created by the subject's 30% effort for each muscle. This allowed us to compare EMG activity across sessions and allowed the assessment of co-contraction. The co-contraction signal of an agonist-antagonist pair was defined as the square root of the instantaneous product of the normalized EMG signal for each muscle in the agonist-antagonist pair. The following pairs were defined: anterior deltoid and lateral deltoid for shoulder flexion/extension, biceps and triceps for elbow flexion/extension and lateral deltoid and pectoralis for shoulder abduction/adduction. One of the main expectations was that subjects would reduce the amount of co-contraction as their shoulder symptoms decreased. Symptom reduction has been anecdotally observed to allow the subjects to "let go" more. Subjects often co-contract to alleviate pain and musculoskeletal symptoms. Further details on the co-contraction index and calculations developed for the current study can be found in Appendix 1.

#### **Data analysis:**

Because of the small sample size, formal statistical analyses were not possible. Instead, data from pre- and post-intervention were compared and trends were noted.

## **Results:**

The results from Study #2 indicated that symptom severity improved in all six subjects from this study who participated in one of the exercise programs. Interestingly, symptom severity also improved in one out of two subjects who participated in the relaxation program. Four out of six subjects who participated in one of the exercise programs also showed an increase in overall lower extremity strength. However, neither of the two subjects in the relaxation program showed any change in overall lower extremity strength or overall upper extremity strength.

There was some evidence that the increase in lower extremity strength was associated with upper extremity unloading, but there was no evidence of a consistent shift in load towards the strengthened lower extremity areas. Many of the subjects with increased lower extremity strength also displayed increased forward trunk lean. Arm release timing and trunk velocity changes were mixed.

Muscle activity in one or more of the major upper extremity muscles that provide propulsion during sit-stand (posterior deltoid, triceps, lateral deltoid) were increased for all seven subjects who displayed upper extremity symptom reduction. Decreased co-contraction was observed in one or more of the upper extremity agonist-antagonist pairs for all study subjects for whom upper extremity symptoms resolved as well as for the subjects for whom symptoms did not change.

## **Discussion:**

The trend towards decreased upper extremity forces with increased lower extremity strength suggests that strengthening the leg muscles may have contributed towards unloading the

arms. However, lack of consistent changes in the lower extremity forces suggested that leg loading was not altered with leg strengthening. The abbreviated duration of the arm use during the sit-stand task, relative to leg use, may help to explain why there was evidence of upper extremity unloading without lower extremity loading changes. It is possible that the lower extremity forces increased during the brief time when the arms were being used.

Another possible explanation for the decreased arm loading by unchanged leg loading stems from the trunk use strategy. Three out of four subjects with increased lower extremity strength also showed increased forward and/or upward velocity, which suggests that they used momentum rather than pushing through the legs to assist in propulsion.

The EMG data were found to be sensitive to the exercise intervention and were supportive of the a-priori hypotheses about mechanism of change. Decreased upper extremity symptoms were associated with increased agonist EMG during sit-stand. Combinations of the triceps, posterior deltoid, and lateral deltoid muscles showed increased activity in all seven subjects for whom upper extremity symptoms resolved. This finding provides some evidence of increased use of active tissue during the sit-stand task.

It should be noted that many of the antagonist muscle groups, as well as some of the agonist groups in the unaffected arms, also showed significant decreases in activity. The pattern of changes, especially in the antagonist muscle use, were not entirely clear. Many of the increases noted above were accompanied by similar decreases in activity of other groups. However, the increased agonist and decreased antagonist activities contributed to supporting the final hypothesis of reduced co-contraction.

The changes in co-contraction that were observed supported the "letting go" phenomenon that is anecdotally observed and reported in the clinic as pain symptoms resolve. In particular,

the biceps-triceps group showed a strong trend towards a reduction in co-contraction. Pain is a major factor associated with subjects employing a “stiffening” strategy. The co-contraction index and the EMG collection and analysis protocol developed for this study helped to quantify changes in muscle utilization strategies. The fact that the other muscle groups showed varying changes in co-contraction indicates that subjects may have selectively varied co-contraction strategies. The exact mechanisms for these changes could not be determined with the existing protocol, but the relative strength of the trends given the small sample size suggests that a follow-up study may be warranted. Variables like joint reaction loads (or “net internal joint loading”) in the upper extremity were not evaluated because the acceleration profiles of the arms did not differ considerably across test sessions. Since kinematic symmetry did not contribute to the clarification of arm use strategy or load shifting between arms and legs, these measures were not analyzed for this report.

## **KEY RESEARCH ACCOMPLISHMENTS**

- Through this research, we were able to determine that musculoskeletal pain in polio survivors is more closely related to activity intensity, rather than activity frequency. Polio survivors push themselves to maintain activity levels that are comparable to older adults without a history of polio. However, since the polio survivors’ maximum performance capacity is lower, the difference between their normal performance level and their maximum performance level is smaller. Therefore, they are at higher risk for overuse problems.
- The results of this study confirmed the link between lower extremity weakness and upper extremity overuse among polio survivors. Body weight was also determined to

be an important factor. However, this relationship did not prove to be generalizable to older adults with no history of polio. We did not find any evidence of an association between age, weight, or strength with presence of shoulder symptoms in the elderly population.

- Data from 54 polio survivors and 54 controls that were matched for gender, race, and bilateral knee extensor strength were compared. The results indicated that musculoskeletal pain was more prevalent among the polio survivors than the matched controls. One possible explanation is that although the polio survivors had similar overall lower extremity strength levels, they were more likely to have more heterogeneity in the strength of individual muscles than the controls. As a result, polio survivors often employ compensation strategies to stabilize their body while performing their daily activities. These compensation strategies may be one cause of the increased number of musculoskeletal symptom in polio survivors.
- Our research looked at the effectiveness of exercise and relaxation therapy on the treatment of shoulder symptoms. Both interventions showed potential as therapies that could be used to treat or even prevent these injuries.
- Through a detailed biomechanical analysis, we did not find support for the hypothesis regarding the correlation between leg strength and changed biomechanics in the sit-stand task. Instead, there seemed to be a better correlation between shoulder symptom resolution and changes in biomechanics. The EMG data and analysis techniques lent support for increased agonist use and decreased co-contraction. However, there were considerable changes in EMG use patterns of other muscles that

were not predicted. The logic for these changes was not apparent, therefore further study is recommended.

## **REPORTABLE OUTCOMES**

### **Manuscripts and Abstracts:**

Klein MG, Keenan MA, Esquenazi A, Costello R, Polansky M. Musculoskeletal pain in polio survivors and strength-matched controls. Arch Phys Med Rehabil 2003 (under review).

Talaty M, Esquenazi A, Klein MG. Changes in sit to stand biomechanics after a muscle strengthening program. Presented at the 8<sup>th</sup> Annual Meeting of Gait and Clinical Movement Analysis Society, April 2003.

Klein MG, Keenan MA, Esquenazi A, Costello R, Polansky M. Factors Related to Musculoskeletal Pain in Polio Survivors and Strength-Matched Controls. Poster Presentation at the 79<sup>th</sup> Annual Meeting of the American Congress of Rehabilitative Medicine, Philadelphia, PA, October 2002.

### **Educational Manual:**

S.O.S. Save our Shoulders: A Guide for Polio Survivors. Philadelphia, PA, June 2003. (Manual was developed as a reference tool for our post-polio subjects and will be distributed to all polio survivors who participated in our research as well as local support groups and post-polio clinics.

## **CONCLUSIONS**

The results of this study help to confirm the relation between lower extremity weakness and shoulder symptoms among polio survivors. Knee extensor strength was identified as an important predictor of shoulder symptoms, with polio survivors with a combined knee extensor strength of less than 59 lb. at highest risk for development of symptoms.

Polio survivors were at higher risk for development of overuse symptoms than the strength-matched controls. Older adults are often encouraged to be as active as possible in order to maintain their functional independence for as long as possible. However, for polio survivors,

there appears to be a fine line between activity levels that are beneficial and help maintain strength versus those that cause overuse problems and result in a further deterioration in strength.

There was no evidence to indicate that the model developed to predict shoulder symptoms among polio survivors could be generalized to older adults with no history of polio. Neither weight nor knee extensor strength were identified as predictors for shoulder symptoms in the elderly population. One possible explanation may be that although older adults without a history of polio have reduced muscle strength due to the effects of normal aging, they usually do not have lower extremity weakness that is as significant as that seen in many polio survivors. Therefore, we can conclude that a different mechanism may exist for development of shoulder symptoms in this population.

The results of this study also indicated that both exercise and relaxation therapies that focus on reducing the stress related to lower extremity weakness may reduce shoulder overuse symptoms. The combined leg and arm exercise group was the only one to show relatively large improvements in both shoulder pain and disability. The results of this study have important implications for polio survivors and others with lower extremity weakness, who rely on their upper extremities to assist with weight-bearing during mobility-related activities.

We originally predicted that strengthening the legs would help reduce stress on the shoulders by partially unloading the arms during a sit-stand task. However, our results showed that increased leg strength allowed subjects to use a mix of strategies to increase propulsion while decreasing arm effort. These strategies included a mix of increased trunk lean and increased trunk velocities. The increased agonist use and changes in the EMG of the antagonist muscles contributed to reduced co-contraction. These data supported that final hypothesis that suggested that subjects would “let go” and show less co-contraction with symptom resolution.

Further study with larger sample sizes is needed before any definitive conclusions about the changes in biomechanics associated with the intervention program can be drawn.

## REFERENCES

1. Klein MG, Whyte J, Keenan MA, Esquenazi A, Polansky M. The relation between lower extremity strength and shoulder overuse symptoms: a model based on polio survivors. *Arch Phys Med Rehabil* 2000; 81: 789-795.
2. Heald SL, Riddle DL, Lamb RL. The shoulder pain and disability index: the construct validity and responsiveness of a region-specific disability measure. *Phys Ther* 1997; 77: 1079-1089.
3. Washburn RA, Smith KW, Jette AM, and Janney CA. The physical activity scale for the elderly (PASE): development and evaluation. *J Clin Epidemiol* 1993, 46: 153-162.
4. Willen C, Cider A, Sunnerhagen KS. Physical performance in individuals with late effects of polio. *Scand J Rehab Med* 1999; 31: 244-249.
5. McHorney CA, Ware JE, Rachel Lu JF, Sherbourne CD. The MOS 36-item short form health survey (SF-36), III: tests of data quality, scaling assumptions, and reliability across diverse patient groups. *Med Care* 1994, 32: 40-46.
6. Borg G. Perceived exertion as an indicator of somatic stress. *Scand J Rehab Med* 1970; 23: 92-98.
7. Klein MG, Whyte J, Keenan MA, Esquenazi A, Polansky M. Changes in strength over time among polio survivors. *Arch Phys Med Rehabil* 2000; 81: 1059-1064.
8. Hassmen P, Kiovuola N, Uutela J. Physical exercise and psychological well-being: a population study in Finland. *Prev Med* 2000; 30: 17-25.
9. Yang JF, Winter DA. Electromyography reliability in maximal and submaximal isometric contractions. *Arch Phys Med Rehabil* 1983; 64: 417-420.



## APPENDIX I

### Co-Contraction Details

A co-contraction index was developed and defined for the present study. The index is a modification of previously reported attempts to quantify co-contraction; an exact such index has not been reported. It is believed the current index provides some advantages over other co-contraction measures. These advantages are summarized below. Mathematically, the index was defined as :

$$CCI = \sqrt{EMG_{agonist}(t) * EMG_{antagonist}(t)}$$

which can be verbalized as the square root of the product of the instantaneous values of the normalized EMG curves of the agonist and antagonist muscles. As such it was calculated individually for the left and right arms of each study subject. Furthermore, it was calculated separately for the biceps-triceps, lateral deltoid-pectoralis, and the anterior deltoid-posterior deltoid groups. This index depended on the individual EMG traces being normalized as was done in the current study. To make comparisons of changes in co-contraction levels across test sessions and due to the exercise program, the average value of the index for each muscle group over the entire propulsion cycle was compared.

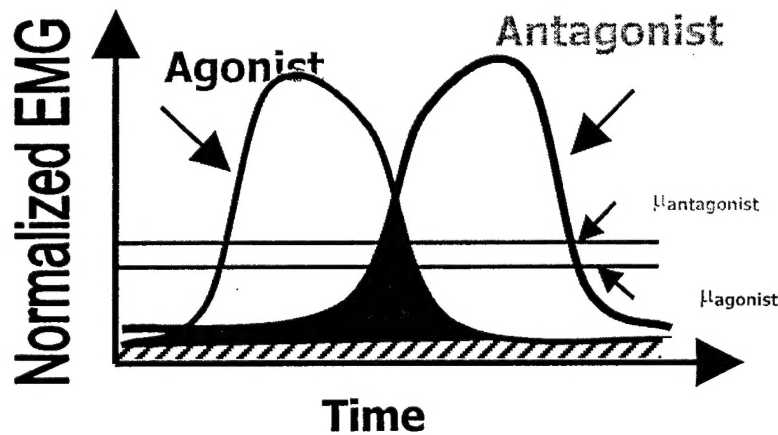


Figure 1. A hypothetical antagonist-agonist EMG trace to help illustrate the advantages and disadvantages of various co-contraction indices. Note, the EMGs shown are assumed to be linear enveloped (full wave rectified and low pass filtered).

Common alternatively defined co-contraction measures including the new index developed for the present study :

1. Average value :  $CCI = \mu_{agonist} * \mu_{antagonist}$

*Advantage* : Does not depend on thresholding of EMG signal; easy to implement; may be possible without sophisticated processing of the EMG signal

*Disadvantage* : Inaccurate when little temporal overlap between EMGs; requires normalized EMG to compare across sessions; does not preserve temporal information

2. Common Area :

$$CCI = \frac{2 * \text{Overlapping Area}}{\text{Area}_{agonist} * \text{Area}_{antagonist}}$$

where the hatched area represents the common area in Figure 1.

*Advantage* : Less inaccurate than mean value when there is little temporal overlap between EMGs

*Disadvantage* : Biased to longer-duration low level activity regions; does not preserve phasic information; more meaningful if calculated from amplitude normalized EMG

3. Instantaneous Product (as used in the current study):

$$CCI = \sqrt{EMG_{agonist}(t) * EMG_{antagonist}(t)}$$

where  $EMG(t)$  is the instantaneous EMG reading at time  $t$

*Advantage* : Biased toward regions when both EMG activities are high; Little overlap regions get lesser weight in final CCI since the product of a large valued EMG and a smaller one is smaller than the product of two large EMGs; the resulting co-contraction trace has a meaningful physical interpretation

*Disadvantage* : Needs normalized amplitudes.

## **APPENDIX II**

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